NUCLEAR EFFECTS IN HIGH ENERGY PHOTON AND NEUTRAL PION PRODUCTION

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We study the mechanism of the γ and π^0 enhancement at large transverse momenta in proton-nucleus collisions. A proposed mechanism suggests an increase in the width of the transverse momentum distribution of partons in a semihard process.

The nuclear enhancement of particle production, known as the Cronin effect, [1] received recent experimental attention by E706, [2] studying the high p_T pion and direct photon production. In this talk we concentrate on direct photon and neutral pion production and propose a new physical mechanism responsible for the increase of the production rate in nuclear targets.

Parton cross sections are calculable in pQCD at high energy to leading order (LO) or next-to-leading-order (NLO).[3] The parton distribution functions (PDFs) and fragmentation functions (FFs), however, need to be fitted to data. In recent NLO calculations the various scales are optimized. [3] Alternatively, an additional non-perturbative parameter, the width of the *intrinsic transverse momentum* (k_T) distribution of the partons is introduced. [4] We choose the latter method and use k_T phenomenologically, expecting that its importance will decrease in higher orders of pQCD.

In the lowest-order pQCD-improved parton model, direct pion production can be described in pA collisions by

$$E_\pi \frac{d\sigma_\pi}{d^3p} = \sum_{abcd} \int d^2b\, t_A(b) \int dx_{1,2} d^2k_{T_{1,2}}\, g_1(\vec{k}_{T_1}, b) g_2(\vec{k}_{T_1}) \qquad (1)$$

$$f_1(x_1, Q^2)\ f_2(x_2, Q^2)\ K \frac{d\sigma}{d\hat{t}} \frac{D(z_c, \widehat{Q}^2)}{\pi z_c}\ ,$$

where $f_1(x, Q^2)$ and $f_2(x, Q^2)$ are the PDFs of partons a and b, and σ is the LO cross section of the appropriate partonic subprocess ($ab \to cd$). The K-factor accounts for higher order corrections. [5] Comparing LO and NLO calculations a nearly constant value, $K \approx 2$, is obtained as a good approximation of the higher order contributions in the p_T region of interest. [6] In eq.(1) $D(z_c, \widehat{Q}^2)$ is the FF of the pion, with $\widehat{Q} = p_T/z_c$, where z_c is the momentum fraction of the final hadron. We use NLO parameterizations of the PDFs[7] and FFs [8] with fixed scales and the partons are assumed to have transverse momenta described by the distribution functions $g_i(\vec{k})$. The nuclear effects are hidden in the impact parameter dependence of this distribution and in the nuclear thickness function $t_A(b) = \int dz\, \varrho(\vec{b}, z)$. Here $\varrho(\vec{r})$ is the density distribution of the nucleus. Direct γ production is described similarly.

In this talk we discuss two idealized density distributions, the homogenous (sharp sphere) nucleus and a Gaussian density profile. The transverse momentum distribution $g(\vec{k}_T)$, is parameterized to be Gaussian, $\exp(-k_T^2/\langle k_T^2\rangle)/\pi\langle k_T^2\rangle$ with a 2-dimensional width of the k_T distribution, $\langle k_T^2\rangle$, related to the average k_T of one parton as $\langle k_T^2\rangle = 4\langle k_T\rangle^2/\pi$. Applying the model to data from $pp \to \pi^0 X$ and $pp \to \gamma X$ experiments we deduced $\langle k_T\rangle_{pp}^{\gamma} = 0.545 \log\sqrt{s} - 0.9$ and $\langle k_T\rangle_{pp}^{\pi} = 0.459 \log\sqrt{s} + 0.092$ in the energy range $\sqrt{s} = 20$–65 GeV. [9]

The standard physical explanation of the nuclear enhancement (Cronin effect) is that the proton traveling through the nucleus gains extra transverse momentum due to random soft collisions and the partons enter the final hard process with this extra k_T.[10] We write the width of the transverse momentum distribution of the partons in the incoming proton as

$$\langle k_T^2\rangle_{pA} = \langle k_T^2\rangle_{pp} + C \cdot h_{pA}(b) \ . \tag{2}$$

Here $h_{pA}(b)$ is the number of *effective* nucleon-nucleon collisions at impact parameter b imparting an average transverse momentum squared C. Naively all possible soft interactions are included, but such a picture leads to a target-dependent C.[9] A more satisfactory description is obtained with a "saturated" h_{pA}, where it takes at most one semi-hard ($Q^2 \sim 1$ GeV^2) collision for the incoming proton to loose coherence, resulting in an increase of the width of its k_T distribution. [9] This is approximated by a smoothed step function with a maximum value of unity. The saturated Cronin factor is denoted by C^{sat}.

i. Sharp sphere nucleus: The thickness function of a sharp sphere nucleus is $t_A(b) = 2\rho_0\sqrt{R_A^2 - b^2}$ with $\rho_0 = 0.16$ fm^{-3}. Calculations show that if all possible soft collisions are included, the momentum square imparted per collision is target dependent, $C^{all}_{pBe} = 0.8 \pm 0.2$, $C^{all}_{pTi} = 0.4 \pm 0.2$ and $C^{all}_{pW} = 0.3 \pm 0.2$ GeV^2. In the saturating model an opposite tendency may be observed with best fits being $C^{sat}_{pBe} = 0.7$, $C^{sat}_{pTi} = 0.85$ and $C^{sat}_{pW} = 1.35$ GeV^2, respectively, however, with much larger tolerance, allowing for a common value, $C^{sat} = 1.1 - 1.2$ GeV^2 to be used in the $pA \to \pi^0 X$ experiment with $A = Be$, Ti and W.[1] Surprisingly, the same value of C^{sat} describes the γ production at $\sqrt{s} \approx 30 - 40$ GeV as well.

ii. Gaussian nucleus: The thickness function of a Gaussian density distribution is $t_A(b) = \varrho_0 e^{-\alpha b^2}\sqrt{\pi/\alpha}$ with $\alpha = \pi(\varrho_0/A)^{2/3}$. For the Be target the maximum value of h_{pA} is below 2 in this case, hence the soft collision and the saturated descriptions are identical. Calculations show that $C^{all}_{pBe} = 1.3 \pm 0.2$, $C^{all}_{pTi} = 0.72 \pm 0.1$ and $C^{all}_{pW} = 0.65 \pm 0.1$ GeV^2. Once again, for the saturated model we have $C^{sat}_{pBe} = 1.3$, $C^{sat}_{pTi} = 1.15$ and $C^{sat}_{pW} = 1.55$ GeV^2, respectively, with large uncertainties. The common value of $C^{sat} = 1.4$ GeV^2 gives a good description of the experiment.

We interpret C^{sat} as the square of the typical transverse momentum imparted in *one* semi-hard collision prior to the hard scattering. Both descriptions could be made consistent with the data on the Ti and W targets, but the soft-collision model is ruled out if we include the whole range of A from Be to W. The proposed mechanism gives better agreement with experimental data, although the extracted value of C^{sat} is slightly target dependent, showing an increase at the heaviest nucleus. This may indicate a contribution from soft collisions. More precise (NLO) calculations are required to analyze this effect. This picture and the energy dependence of C^{sat} need to be tested as functions of A at different energies.

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